

Mon. Not. R. Astron. Soc. **322**, 257–261 (2001)

# The connection between globular cluster systems and the host galaxies

Duncan A. Forbes<sup>1,2★</sup> and Juan C. Forte<sup>2★</sup><sup>1</sup>*Astrophysics & Supercomputing, Swinburne University, Hawthorn, VIC 3122, Australia*<sup>2</sup>*Facultad de Ciencias Astronomicas y Geofisicas, Universidad Nacional de La Plata, Paseo del Bosque, 1900 La Plata, Argentina and CONICET*

Accepted 2000 September 25. Received 2000 September 25; in original form 2000 March 13

## ABSTRACT

A large number of early-type galaxies are now known to possess blue and red subpopulations of globular clusters. We have compiled a data base of 28 such galaxies exhibiting bimodal globular cluster colour distributions. After converting to a common  $V-I$  colour system, we investigate correlations between the mean colour of the blue and red subpopulations with galaxy velocity dispersion. We support previous claims that the mean colours of the blue globular clusters are unrelated to their host galaxy. They must have formed rather independently of the galaxy potential they now inhabit. The mean blue colour is similar to that for halo globular clusters in our Galaxy and M31. The red globular clusters, on the other hand, reveal a strong correlation with galaxy velocity dispersion. Furthermore, in well-studied galaxies the red subpopulation has similar, and possibly identical, colours to the galaxy halo stars. Our results indicate an intimate link between the red globular clusters and the host galaxy; they share a common formation history. A natural explanation for these trends would be the formation of the red globular clusters during galaxy collapse.

**Key words:** globular clusters: general – galaxies: elliptical and lenticular, cD – galaxies: evolution – galaxies: interactions.

## 1 BACKGROUND MOTIVATION

Globular clusters are relatively homogeneous entities containing stars of a single age and metallicity. Although we do not fully understand the relative efficiency of forming globular cluster (GC) stars over galactic field stars, there is good evidence that when a starburst occurs in a galaxy, GCs will also form (e.g. Ho 1997). Thus GCs can provide a unique probe of the star formation and chemical enrichment history of galaxies. To exploit this ‘probe’ fully one needs to have an idea for how GCs form in galaxies. Current scenarios include mergers (Schweizer 1987; Ashman & Zepf 1992), two phase collapse (Forbes, Brodie & Grillmair 1997) and tidal stripping/accretion (Forte, Martinez & Muzzio 1982; Cote, Marzke & West 1998).

A direct comparison of GC and host galaxy colours was first attempted in the late 1970s and early 1980s (e.g. Hanes 1977; Forte, Strom & Strom 1981). A difference in colour was observed, in the sense that GCs were  $\sim 0.5$  dex more metal-poor than galaxy stars. This led Forte et al. (1981) to conclude that ‘...the chemical enrichment history of the globular cluster system and of the spheroidal component must have differed, and that the globular clusters are likely to form a component dynamically as well as chemically distinct from the spheroid.’

However, another line of argument has developed indicating that there *is* a link between GCs and their host galaxy. This involves the correlation between the mean metallicity of the GC system and galaxy luminosity. Such a trend was first suggested by van den Bergh (1975) and shown by Brodie & Huchra (1991), but for only 10 galaxies. It was later disputed by Ashman & Bird (1993) claiming that there was no correlation, and by Perelmuter (1995) claiming that the relation only existed for spirals. In 1996, Forbes et al. showed a strong trend over 10 mag for 35 early-type galaxies. Subsequent larger samples have confirmed a correlation (e.g. Durrell et al. 1996). Although the scatter is large, a linear fit has a slope very similar to that for the galaxy stellar metallicity versus galaxy luminosity relation, i.e.  $Z \propto L^{0.4}$  (see Brodie & Huchra 1991).

The galaxy relations, like the  $M_{g_2} - \sigma$  and the colour–magnitude relations, are generally believed to be correlations of metallicity and mass (Kodama & Arimoto 1997; Forbes, Ponman & Brown 1998a). Thus, by analogy, the mean metallicity of the GC system ‘knows about’ the mass of the galaxy in which it resides; *the chemical enrichment of GCs is directly linked to the galaxy formation process.*

It wasn’t until the 1990s that we could easily understand the apparent metallicity difference between the GC system and the host galaxy (as noted by Forte et al. 1981) – it is due to the presence of two distinct GC subpopulations (e.g. Lee & Geisler 1993). The metallicity difference is a result of the relative mix of metal-rich

★ E-mail: [dforbes@swin.edu.au](mailto:dforbes@swin.edu.au) (DAF); [forte@iafe.uba.ar](mailto:forte@iafe.uba.ar) (JCF)

and metal-poor GC subpopulations. It appears that the metal-rich GCs have a mean metallicity that is similar to the host galaxy stars with the metal-poor ones  $\sim 1$  dex lower (e.g. Geisler, Lee & Kim, 1996; Forbes, Brodie & Huchra 1997). In the Forte et al. (1981) study, their sampling was dominated by the blue GCs, leading them to suggest that the GC system and the host galaxy were ‘distinct’.

Revisiting the metallicity–luminosity relation, Forbes et al. (1997) showed that for 11 GC systems the metallicity of the metal-rich population correlated with galaxy luminosity, but the metal-poor one did not (see also Burgarella, Kissler-Patig & Buat 2000). Forbes et al. (1997) concluded that only the metal-rich GCs were closely linked to the formation process of the galaxy.

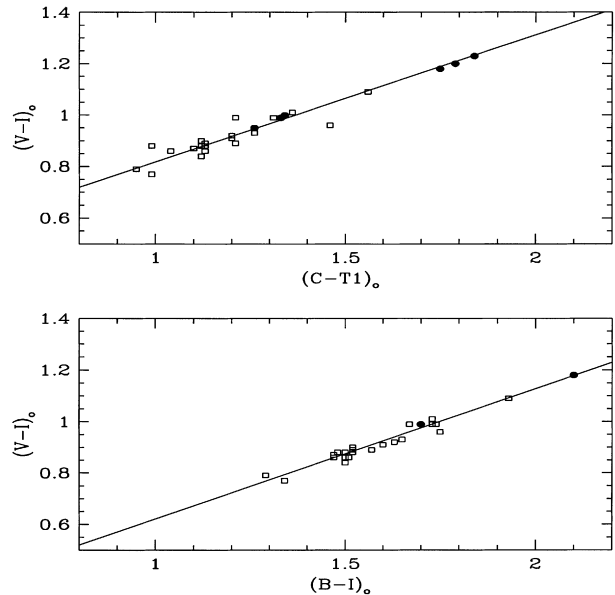
However, one caveat about the interpretation of the GC metallicity–galaxy luminosity relation is that metallicities are usually based on colours that have been converted into  $[\text{Fe}/\text{H}]$  assuming a Galactic relation. This has two limitations: (i) The Galactic relation is strictly only valid for very old GCs. The limited current evidence suggests that GCs around ellipticals are indeed very old (Kissler-Patig et al. 1998; Cohen, Blakeslee & Rhyzov 1998; Puzia et al. 1999), but this may not always be the case. (ii) Few Galactic GCs have solar or supersolar metallicities, whereas this is often the case for elliptical galaxy GCs. Recently a conversion from  $V-I$  to supersolar metallicities has been derived by Kissler-Patig et al. (1998), but it is still somewhat uncertain for other colour systems.

So, although it seems fairly probable that the metal-rich GCs formed from gas that has been processed within the potential well of the galaxy, previously arguments relied on the assumption that the Galactic relation is applicable. In this paper, we use direct measurements of GC colours and compare these with galaxy internal velocity dispersions for a sample of 28 galaxies. Our approach alleviates some of the problems associated with metallicity–luminosity relations mentioned above. In addition, we avoid the distance dependence present in the metallicity–luminosity relation. We also examine the GC and galaxy halo colours in detail for a few individual galaxies. We find that the mean colour of the red GCs correlates with galaxy velocity dispersion. Furthermore, in well-studied galaxies the mean colour of the red GCs is almost identical to that of the galaxy halo (bulge) stars. We briefly discuss the implications of our findings for GC formation scenarios.

## 2 CONVERSION TO A SINGLE COLOUR SYSTEM

The bulk of high-quality GC colours, available in the literature, come from *Hubble Space Telescope* (*HST*) studies, and most of these use the F555W ( $V$ ) and F814W ( $I$ ) filters. Although this choice of filters does not provide as much metallicity ‘leverage’ as, say,  $B-I$  or  $C-T1$  (on the Washington system), a large number of early-type galaxies are now known to possess GC systems with bimodal  $V-I$  colour distributions. Several more are known from observations in other colour systems. Before compiling a homogeneous dataset of GC colours we need to convert the bimodality seen using other colour systems into  $V-I$ . We will use a  $V-I$  versus colour relation based on Galactic GCs; however, we first need to confirm that it is applicable for the GC systems of early-type galaxies.

In Fig. 1 we show the extinction corrected  $(V-I)_0$  versus  $(C-T1)_0$  and  $(B-I)_0$  colour for Galactic GCs with low reddenings



**Figure 1.**  $(V-I)_0$  versus  $(C-T1)_0$  and  $(B-I)_0$  colour relation for Galactic globular clusters. Open squares represent Galactic globular clusters with low reddening, and filled circles the blue and red globular cluster populations of NGC 1399, 4472 and NGC 4486. The solid line is a fit to the Galactic globular clusters only.

[i.e.  $E(B-V) < 0.1$ ] taken from Reed, Hesser & Shaw (1988) and Harris & Cantnera (1977). The best bisector fits are shown by a solid lines. We have also made a fit to transform  $B-R$  to  $V-I$  (not shown in Fig. 1). The fits are the following:

$$(V-I)_0 = 0.49(C-T1)_0 + 0.32,$$

$$(V-I)_0 = 0.51(B-I)_0 + 0.11,$$

$$(V-I)_0 = 0.68(B-R)_0 + 0.15.$$

The typical rms about the fits is  $\pm 0.03$  mag. Thus one could expect to estimate  $V-I$  for a Galactic type GC with an accuracy of  $\sim 0.03$  mag from a different colour.

Fig. 1 also shows the mean blue and red colours for the GCs in the well-studied galaxies NGC 1399, NGC 4472 (M49) and NGC 4486 (M87). Here we have plotted the  $(C-T1)_0$  measurements for NGC 1399 (Ostrov, Forte & Geisler 1998), NGC 4472 (Geisler et al. 1996), and NGC 4486 (Lee & Geisler 1993) and the  $(B-I)_0$  values for NGC 1399 (Forbes et al. 1998a). The corresponding  $(V-I)_0$  values are NGC 1399 (Kissler-Patig et al. 1997a), NGC 4472 (Puzia et al. 1999) and NGC 4486 (Kundu et al. 1999). The GC systems of these galaxies are consistent with the Galactic relation, including an extrapolation to redder (more metal-rich) colours. Thus we feel confident in our transformation from  $C-T1$  and  $B-I$  into  $V-I$ . We do not have any independent confirmation of the  $B-R$  transformation but have no reason to doubt that it too is applicable to GCs in ellipticals.

In Table 1 we list the mean  $(V-I)_0$  colours for the GC subpopulations in 28 galaxies. Of these, only four have been transformed from other colour systems (as noted in Table 1). The estimated photometric errors for the mean colours are typically  $\pm 0.05$  mag (this includes the uncertainty of transformation from one colour system to  $V-I$ ). The confidence of bimodality is given by ‘Yes’ for definite and ‘Likely’ for probable. In most cases the statistical significance of the bimodality can be found in the original reference.

**Table 1.** Blue and red globular cluster ( $V-I$ )<sub>0</sub> colours

Galaxy Name	Blue Peak	Red Peak	Bimodal	Ref.
NGC 584	$0.98 \pm 0.05$	$1.18 \pm 0.05$	Likely	K99
NGC 1023	$0.92 \pm 0.05$	$1.17 \pm 0.05$	Yes	LB00
NGC 1380	$0.86 \pm 0.10$	$1.10 \pm 0.10$	Yes	KK97 <sup>a</sup>
NGC 1399	$0.99 \pm 0.05$	$1.18 \pm 0.05$	Yes	KR97
NGC 1404	$0.93 \pm 0.10$	$1.18 \pm 0.10$	Yes	F98 <sup>b</sup>
NGC 1427	$0.98 \pm 0.05$	$1.16 \pm 0.05$	Yes	F00 <sup>c</sup>
NGC 1439	$0.97 \pm 0.05$	$1.16 \pm 0.05$	Likely	K99
NGC 2768	$0.92 \pm 0.05$	$1.12 \pm 0.05$	Yes	K99
NGC 3115	$0.96 \pm 0.05$	$1.17 \pm 0.05$	Yes	KW98
NGC 3311	$0.91 \pm 0.05$	$1.09 \pm 0.05$	Yes	B00
NGC 3377	$0.96 \pm 0.05$	$1.13 \pm 0.05$	Likely	K99
NGC 3379	$0.94 \pm 0.05$	$1.16 \pm 0.05$	Likely	K99
NGC 3923	$1.04 \pm 0.10$	$1.24 \pm 0.10$	Yes	Z95 <sup>c</sup>
NGC 4278	$0.93 \pm 0.05$	$1.13 \pm 0.05$	Likely	K99
NGC 4406	$0.98 \pm 0.05$	$1.17 \pm 0.05$	Likely	K99
NGC 4472	$1.00 \pm 0.05$	$1.23 \pm 0.05$	Yes	P99
NGC 4473	$0.93 \pm 0.05$	$1.15 \pm 0.05$	Yes	K99
NGC 4486	$0.95 \pm 0.05$	$1.20 \pm 0.05$	Yes	KW99
NGC 4494	$0.95 \pm 0.05$	$1.15 \pm 0.05$	Yes	F96
NGC 4526	$0.85 \pm 0.05$	$1.15 \pm 0.05$	Yes	GK99
NGC 4552	$0.96 \pm 0.05$	$1.18 \pm 0.05$	Likely	K99
NGC 4621	$0.98 \pm 0.05$	$1.16 \pm 0.05$	Yes	K99
NGC 4649	$0.95 \pm 0.05$	$1.20 \pm 0.05$	Yes	K99
NGC 4660	$0.93 \pm 0.05$	$1.08 \pm 0.05$	Likely	K99
NGC 5846	$0.96 \pm 0.05$	$1.17 \pm 0.05$	Yes	F97
NGC 5982	$0.99 \pm 0.05$	$1.18 \pm 0.05$	Likely	K99
IC 1459	$1.00 \pm 0.05$	$1.25 \pm 0.05$	Yes	F96
IC 4051	$1.00 \pm 0.05$	$1.17 \pm 0.05$	Likely	WH00

<sup>a</sup> = transformed from  $B-R$ ;<sup>b</sup> = transformed from  $B-I$ ;<sup>c</sup> = transformed from  $C-T1$ .

B00 = Brodie et al. (2000); F96 = Forbes et al. (1996); F97 = Forbes et al. (1997); F98 = Forbes et al. (1998); F00 = Forte et al. (2001); GK99 = Gebhardt & Kissler-Patig (1999); KK97 = Kissler-Patig et al. (1997b); KR97 = Kissler-Patig et al. (1997a); KW98 = Kundu & Whitmore (1998); K99 = Kundu (1999); KW99 = Kundu et al. (1999); LB00 = Larson & Brodie (2000); P99 = Puzia et al. (1999); Z95 = Zepf et al. (1995); WH00 = Woodworth & Harris (2000).

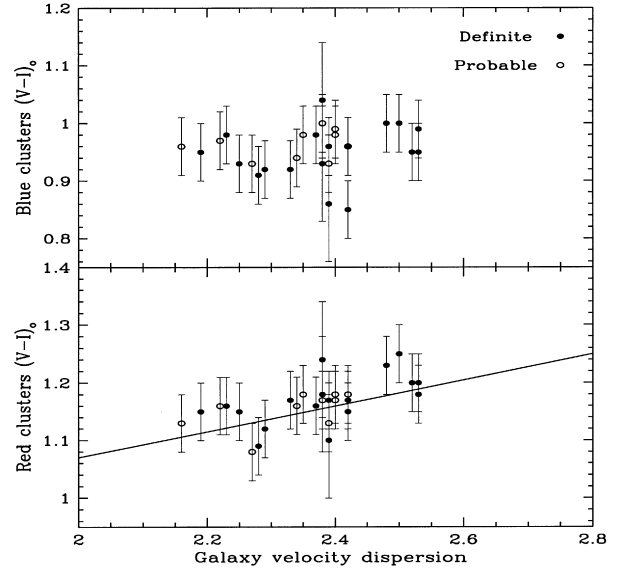
### 3 RESULTS AND DISCUSSION

#### 3.1 Trends with velocity dispersion

In Fig. 2 we show the mean ( $V-I$ )<sub>0</sub> colour of the GC subpopulations versus the galaxy velocity dispersion for all of the galaxies listed in Table 1. The velocity dispersion data come from Prugniel & Simien (1996).

The blue GCs show no correlation with galaxy velocity dispersion. Indeed they reveal a fairly constant colour of ( $V-I$ )<sub>0</sub> =  $0.954 \pm 0.008$ . This is very similar to the overall mean colours of the Milky Way ( $0.94 \pm 0.01$ ) and M31 ( $0.96 \pm 0.01$ ) GC systems (see Barmby et al. 2000). If we exclude the disc/bulge populations of GCs in these spirals, then the halo GCs in both galaxies have a mean ( $V-I$ )<sub>0</sub>  $\sim 0.92$  (Barmby et al. 2000). Thus the blue GCs in spirals and early-type galaxies have a very similar age and metallicity, but there are hints that those in spirals may be slightly younger and/or more metal-poor.

The red GCs, on the other hand, reveal a strong correlation (at  $3\sigma$  significance) of mean colour with galaxy velocity dispersion. The best-fitting line for the red GCs ( $V-I = 0.23 \log \sigma + 0.61$ ) is shown in Fig. 2. Galaxy velocity dispersion is a tracer of galaxy mass. Thus the colour (and presumably metallicity) of the red GCs is directly linked to the depth of the galaxy's potential well. We note that if we had converted the  $C-T1$  measurements of Secker



**Figure 2.** Colour of globular cluster subpopulations versus log of the galaxy velocity dispersion. Solid circles are galaxies with definite bimodal globular cluster colours, and open circles are probable bimodal systems. A  $3\sigma$  correlation exists between globular cluster mean colour and velocity dispersion for the red subpopulation but not for the blue subpopulation.

et al. (1995) for NGC 3311 then the colours of the blue ( $V-I = 1.15$ ) and red ( $V-I = 1.28$ ) GCs would deviate strongly from the trends seen in Fig. 2. However, we used the more recent results of Brodie, Larson & Kissler-Patig (2000) which indicate normal GC colours for NGC 3311. We suspect zero-point errors in the Secker et al. (1995) analysis. This may also affect the  $C-T1$  colours (Zepf, Ashman & Geisler 1995) for the NGC 3923 GC system which was observed on the same run (we have assigned it a larger error). Indeed NGC 3923 is one of the more deviant points in Fig. 2.

#### 3.2 Trends with galaxy halo colour

Having shown that the red GC subpopulation has a direct connection with the host galaxy, while the blue subpopulation is unconnected, we now explore the trend between mean GC colour and galaxy halo colour.

In order to make the best comparison of GC and galaxy colours, the colours should come from the same observations, and sample a similar galactocentric annulus around any given galaxy as radial gradients may exist in the galaxy and GC subpopulations (e.g. Ostrov et al. 1998; Forte et al. 2001). We have also decided to restrict our analysis to the wide-area studies conducted using  $C-T1$  (which has the best metallicity sensitivity of GC studies). This excludes *HST* studies which typically probe only the galaxy inner regions in  $V-I$ .

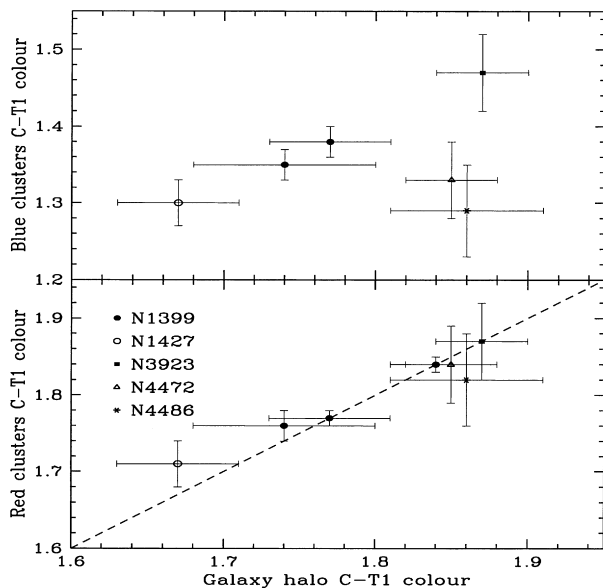
With these criteria we found five galaxies [the Secker et al. (1995)  $C-T1$  data on NGC 3311 has been excluded for reasons mentioned above]. The five are NGC 1399 (Ostrov et al. 1998), NGC 1427 (Forte et al. 2001), NGC 3923 (Zepf et al. 1995), NGC 4472 (Geisler et al. 1996) and NGC 4486 (Geisler et al., in preparation). We note that the zero-points and hence colours of NGC 3923 may be in error (as discussed above), but as the galaxy and GCs colours come from the same observation this will not

effect the relative colour difference. The two papers referenced for NGC 4472 use the same data collected in 1993. Where possible, colours have been taken from similar galactocentric radii. In the case of NGC 1399, Ostrov et al. (1998) quote galaxy and GC colours in three radial bins for the red subpopulation and two bins for the blue ones.

The mean GC colours versus galaxy halo colour is shown in Fig. 3. The mean blue GC colours do not reveal a strong trend with halo colour, and in particular lie well away from a one-to-one relation. However, the red GCs *do* lie close to a one-to-one relation. Within the errors, the red GCs have identical  $C-T1$  colours to those of their host galaxy. So not only do red GCs have a metallicity that is linked to the depth of the galaxy's potential well (Fig. 2), but for at least *some* galaxies they also have the same metallicity as the galaxy halo stars. This suggests a very well coordinated star formation and chemical enrichment history.

For the NGC 1399 red GCs, the agreement is not only restricted to the mean colours discussed above, but also in the sense that they share the same colour gradient as the underlying galaxy halo (see Table 5 in Ostrov et al. 1998). If the galaxy halo were in fact related to the *overall* GC system, then halo colour gradients would reflect the varying ratio of the blue to red GCs with galactocentric radius. However, if this were the case, we would expect the halo colour gradient to get significantly bluer with increasing radius (as the blue GCs dominate). For NGC 1399 (Ostrov et al. 1998) this is not the case, indicating that the halo colours do not reflect the blue GCs, but rather reflect the red ones.

Finally, we note that in recent ground-breaking work, Harris, Harris & Poole (1999) used *HST* to resolve the stars in the halo of NGC 5128. They showed that the red halo stars and the metal-rich GCs have the same metallicity, and concluded that they formed in the same star formation event.



**Figure 3.** Mean  $C-T1$  colour of the globular clusters and galaxy halo. Globular cluster and galaxy colours are taken from the same source, and matched in galactocentric radius where possible. For NGC 1399 colours at different galactocentric radii are shown. See text for details. The dashed line shows a one-to-one relation. Within the errors, red globular clusters have identical  $C-T1$  colours to the host galaxy halo.

### 3.3 How did the red globular clusters form?

The simplest explanation for the fact that the red GCs and the galaxy stars may have similar colours, and that red GCs colours correlate with galaxy velocity dispersion, is that they formed at the same time from the same chemically enriched gas. This would naturally favour the two-phase collapse scenario (Forbes et al. 1997). In this scenario the red GCs form almost contemporaneously with the galaxy field stars, and hence share their properties. The trends described here are a natural consequence of this idea.

Are these trends expected in the merger picture (Ashman & Zepf 1992)? After a gaseous merger the galaxy will consist of at least two stellar and two GC populations (the first associated with the progenitor galaxies and the other created in the merger). The relative ratios of these two components depend on how much gas is available to create the new stars and GCs. The gas fraction would be high at early epochs. To explain Fig. 2 one could argue that the more metal-rich (redder) GCs formed in the larger (higher velocity dispersion) galaxies. However, to explain the nearly identical colours of the galaxy halo and red GCs (Fig. 3), one must then argue that the halo is dominated by new stars formed at the same time, from the same gas, as the new (red) GCs. This would imply that the progenitors were largely gaseous and hence the merger occurred at high redshift. The distinction between the merger and collapse pictures becomes blurred. Various other difficulties for the merger model are discussed in detail by Forbes et al. (1997).

In the accretion model of Cote et al. (1998), the red GCs form *in situ* but the blue ones are accreted, along with starlight, from stripped dwarf galaxies. This accumulation of metal-poor material into the halo of the primary galaxy would tend to make the halo light bluer than the red GCs – in contradiction to what is seen in Fig. 3.

## 4 CONCLUDING REMARKS

Here we have presented evidence that the mean colours of the blue GCs in early-type galaxies are unrelated to their host galaxy, supporting the work of Forbes et al. (1997) and Burgarella et al. (2000). In terms of a collapse scenario, where the blue GCs form in proto-galactic dark matter halos, they do not appear to have ‘memory’ of the collapse phase, suggesting they formed pre-collapse or possibly quite independently of the eventual host galaxy (Burgarella et al. 2000). We note however, that this is probably not true for the Milky Way halo globular clusters (the ‘blue’ subpopulation). These metal-poor globular clusters *do* show evidence that the majority formed within our Galactic halo (van den Bergh 1996).

The red GCs, on the other hand, do ‘know’ about the galaxy they occupy in terms of its potential well and halo colour. This suggests that the red GCs and the host galaxy share a common formation event. This naturally favours the two-phase collapse picture, in which the red GCs and the halo stars are formed together (Forbes et al. 1997). The merger picture (Ashman & Zepf 1992) is only compatible if the merger took place at early epochs involving gaseous progenitors.

## ACKNOWLEDGMENTS

We thank A. Georgakakis, S. Larsen and S. van den Bergh for

useful discussions. S. Larsen also kindly provided results on NGC 3311 before publication. DAF thanks La Plata Observatory for their hospitality during 1999 August when much of the work was carried out. Finally we thank the referee J. Brodie for her many useful comments and suggestions.

## REFERENCES

- Ashman K. M., Zepf S. E., 1992, *ApJ*, 384, 50  
 Ashman K. M., Bird C. M., 1993, *AJ*, 106, 2281  
 Barmby P., Huchra J. P., Brodie J. P., Forbes D. A., Schroder L. L., Grillmair C. J., 2000, *AJ*, 119, 727  
 Brodie J. P., Huchra J. P., 1991, *ApJ*, 379, 157  
 Brodie J. P., Larson S., Kissler-Patig M., 2000, *ApJ*, 543, L19  
 Burgarella D., Kissler-Patig M., Buat V., 2000, *A&A*, in press  
 Cohen J. G., Blakeslee J. P., Rhyzov A., 1998, *ApJ*, 496, 808  
 Cote P., Marzke R. O., West M. J., 1998, *ApJ*, 501, 554  
 Durrell P. R., Harris W. E., Geisler D., Pudritz R. E., 1996, *AJ*, 112, 972  
 Forbes D. A., Franx M., Illingworth G. D., Carollo C. M., 1996, *ApJ*, 467, 126  
 Forbes D. A., Brodie J. P., Grillmair C. J., 1997, *AJ*, 113, 1652  
 Forbes D. A., Grillmair C. J., Williger G. M., Elson R. A. W., Brodie J. P., 1998a, *MNRAS*, 293, 325  
 Forbes D. A., Ponman T. J., Brown R. J. N., 1998b, *ApJ*, 508, L43  
 Forbes D. A., Brodie J. P., Huchra J., 1997, *AJ*, 113, 887  
 Forte J., Geisler D., Ostrov P., Piatti A., Gieren W., 2001, *AJ*, in press  
 Forte J. C., Strom S. E., Strom K. M., 1981, *ApJ*, 245, L9  
 Forte J. C., Martinez R. E., Muzzio J. C., 1982, *AJ*, 87, 1465  
 Gebhardt K., Kissler-Patig M., 1999, *AJ*, 118, 1526  
 Geisler D., Lee M. G., Kim E., 1996, *AJ*, 111, 1529  
 Hanes D., 1977, *MNRAS*, 179, 331  
 Harris H., Canterna R., 1977, *AJ*, 82, 798  
 Harris G., Harris W. E., Poole G. B., 1999, *AJ*, 117, 855  
 Ho L., 1997, *Rev. Mex. Astron. Astrofis.*, 6, 5  
 Kissler-Patig M., Kohle S., Hilker M., Richtler T., Infante L., Quintana H., 1997a, *A&A*, 319, 470  
 Kissler-Patig M., Richtler T., Storm M., Della Valle M., 1997b, *A&A*, 327, 503  
 Kissler-Patig M., Brodie J. P., Forbes D. A., Grillmair C. J., Huchra J. A., 1998, *AJ*, 115, 105  
 Kodama T., Arimoto N., 1997, *A&A*, 320, 41  
 Kundu A., Whitmore B. C., 1998, *AJ*, 116, 2841  
 Kundu A., Whitmore B. C., Sparks W. B., Machetto F. D., Zepf S. E., Ashman K. M., 1999, *AJ*, 515, 733  
 Kundu A., 1999, PhD Thesis, Univ. Maryland  
 Larson S., Brodie J. P., 2000, *AJ*, submitted  
 Lee M. G., Geisler D., 1993, *AJ*, 106, 493  
 Ostrov P. G., Forte J. C., Geisler D., 1998, *AJ*, 116, 2854  
 Prugniel P., Simien F., 1996, *A&A*, 309, 749  
 Perelmuter J. M., 1995, *ApJ*, 454, 762  
 Puzia T., Kissler-Patig M., Brodie J. P., Huchra J. P., 1999, *AJ*, 118, 2734  
 Reed B. C., Hesser J. E., Shawl S. J., 1988, *PASP*, 100, 545  
 Secker J., Geisler D., McLaughlin D. E., Harris W. E., 1995, *AJ*, 109, 1019  
 Schweizer F., 1987, in Faber S., eds, *Nearly Normal Galaxies*. Springer, New York, p. 18  
 van den Bergh S., 1975, *ARA&A*, 13, 217  
 van den Bergh S., 1996, *PASP*, 108, 986  
 Woodworth S. C., Harris W. E., 2000, *astro-ph/0002292*  
 Zepf S. E., Ashman K. E., Geisler D., 1995, *ApJ*, 443, 570

This paper has been typeset from a  $\text{\LaTeX}$  file prepared by the author.